A COMPARISON OF SOLENOID-BASED STRATEGIES FOR ROBOTIC DRUMMING

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ABSTRACT

Solenoids are important components of robotic drumming systems and several designs have been proposed. In this paper, we compare different designs in terms of speed and dynamic range and discuss the tradeoffs involved. The evaluation is performed in the context of *MahaDeviBot*, a custom built 12-armed MIDI controlled mechanical device that performs a variety of Indian folk instruments, including frame-drums, bells, and shakers. To measure speed and dynamic range a haptic robotic feedback system using piezo sensors was built. The evaluation methods presented are modular and can be administered to any hyperinstrument, new interface or robotic system to inform composers about the strengths and limitation of different designs to guide composition and performance.

1. INTRODUCTION

Mechanical systems for musical expression have developed since the 19th Century. Before the phonogram, player pianos and other automated devices were the only means of listening to compositions, without the presence of live musicians. The invention of audio recording tools eliminated the necessity and progression of these types of instruments. In modern times, with the invention of the microcontroller and inexpensive electronic actuators, mechanical music is being revisited by many scholars and artists.

Musical robots have come at a time when tape pieces and laptop performances have left some in the computer music audiences wanting more interaction and physical movement from the performers. The research in developing new interfaces for musical expression continues to bloom as the community is now beginning to focus on how actuators can be used to push the bar even further, creating new mediums for creative expression. Robotic systems can perform tasks not achievable by a human musician. The sound of a bell being being struck on stage with its acoustic resonances with the concert hall can never be replaced by speakers, no matter how many directions they point. The use of robotic systems as pedagogical implements is also proving to be significant. Indian Classical students practice to a Tabla box with pre-recorded drum loops. The use of robotic strikers, performing real acoustic drums gives the students a more realistic paradigm for concentrated rehearsal.

A number of different drumming robots have been designed in the academic and artistic communities. Researchers at Harvard University struggled to create an accurate robotic drum roll [1], while next door researchers at MIT developed Cog to control the number of times a stick can bounce [2]. Gil Weinberg developed Haile to explore human to robot interaction [3]. Mitsuo Kawato continues to develop hydraulic systems for humanoid drumming [4]. Many artists have presented a number of different pieces including Baginsky's “Thelxiapeia” for modified rototom [5], MacMurtie's life size sculptures [6], Gordon Monohans “Machine Matrix” [7], and Miles van Dorssen's “Cell Project” including an 8 octave Xylophone, Bamboo Rattle, gong, high-hat and bells [8]. The second and third authors have also had significant contributions to the evolution of robotic drumming [9-11].

The above drumming robots have all been one of a kind proof of concept systems and there hasn't been much work in qualitative comparative evaluation of different designs. Our goal in this paper is to explore systems that can be used in the classroom to teach musical robotics. Therefore, we choose to focus on solenoid-based designs as hydraulic-based designs have prohibitive cost for classroom use. The designs presented are practical and can be replicated in a semester. The evaluation methods presented are important to inform composers and designers about strengths and limitations of different designs to guide composition decisions and performance constraints.

The development of the *MahaDeviBot* as a paradigm for various types of solenoid-based robotic drumming is described. Section 2 defines a solenoid in detail including circuit diagrams for reference. Section 3 describes the design strategies for the *MahaDeviBot*, including 5 different methods for using solenoids for rhythmic events. Section 4 presents the experimental evaluation of speed and dynamic testing of the different design methods. Section 5 draws conclusions and postulates future directions.

2. SOLENOID

A solenoid [12] is a special type of motor which creates linear motion. It consists of a coil of wire with an iron shaft in the center. When current is supplied to the coil, a magnetic field is created and the shaft is pushed. When the current is removed, the magnetic field is no longer present and the shaft returns to its original position. The time period between supplying current and turning it off must be short or the solenoid will overheat and stop working. The more voltage supplied to the solenoid, the harder it will strike down. Thus it can be used in conjunction with Pulse Width Modulation (PWM) to supply variable control of striking power.

The circuit diagram for operating a solenoid is shown in Figure 1. When a coil of wire is moving in a magnetic field, it induces a current in the wire. Thus when the motor is spinning near a magnet and then is turned off, the magnetic field induces a current in the wire for a brief time. This back voltage can damage electronics, especially the microcontroller. Thus a snubber diode is used to block the current from going the wrong way. Also a transistor is used to switch the higher voltage power of the motor to the low voltage power of the microcontroller. There are two types of solenoids, ones that can pull (Figure 3) and ones that push (Figure 2).

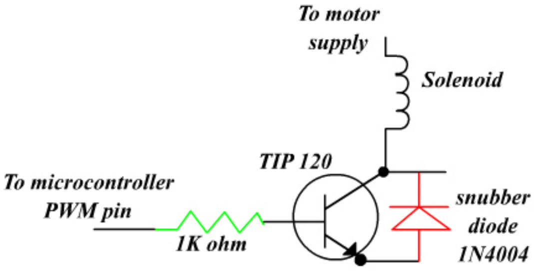

Figure 1 - Circuit diagram for a using a Solenoid.

3. DESIGN

Different solenoid-based designs for robotic dumming are evaluated in the context of *MahaDeviBot,* a 12 armed robotic drummer which performs instruments from India including frame drums, bells, and shakers. Four different methods for solenoid-based drumming are described. A robotic head of *MahaDeviBot* is also described. Finally we present a piezo-based haptic feedback system for evaluation experiments and machine's awareness of its own parts.

3.1. Arms

There are four different designs proposed by the first 3 authors, and appropriately named: Kapur Fingers, Singer Hammer, Trimpin Hammer and Trimpin BellHop and are described.

3.1.1. Kapur Fingers

The Kapur Fingers involve modifications of a push solenoid. One issue with the off-the-shelf versions of the solenoids is that during use they click against themselves making lots of mechanical sound. A key goal for a successful robotic system is to reduce the noise of its parts so it does not interfere with the desired musical sound. Thus the push solenoids were taken apart to reduce noise. The shaft and inner tubing were buffed with a wire spinning mesh using a dremel. Then protective foam was placed toward the top of the shaft to stop downward bounce clicking. Grommets were attached in order to prevent upward bounce-back clicking. The grommets were also used to simulate the softness of the human skin when striking the drum as well as to protect the drum skin.

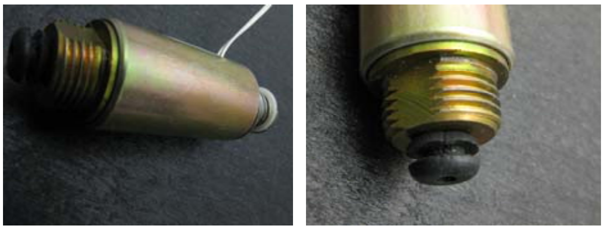

Figure 2 - Kapur Finger using a grommet and padding.

3.1.2. Singer Hammer

The Singer Hammer is a modified version of the third author's ModBot [10]. The mechanism strikes a drum using a steel rod and ball. A pull solenoid is used to lift a block that the rod is attached to. The first author added a ball joint system to connect the solenoid to the bar, for security and reliability of strokes. The trade-off was that it added some mechanical noise to the system.

Figure 3 - Singer Hammer with added ball-joint striking mechanism.

3.1.3. Trimpin Hammer

The Trimpin Hammer is a modified version of the second author's variety of percussion instruments invented over the last 20 years [11]. Its key parts include female and male rod ends, and shaft collars. This is a very robust system which involves using a lathe to tap the shaft of the solenoid so a male rod end can be secured. This is a very mechanically quiet device, especially with the added plastic stopper to catch the hammer on the recoil.

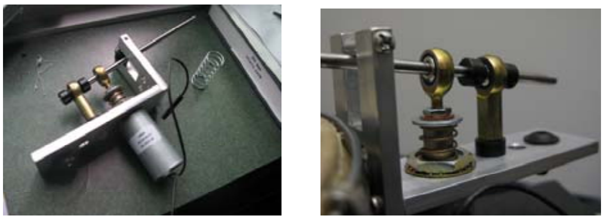

Figure 4 - Trimpin Hammer modified to fit the MahaDeviBot schematic.

3.1.4. Trimpin BellHop

The Trimpin BellHop is a modified version of the second author's ColoninPurple, where 30 such devices were used to perform modified xylophones suspended in the air of a gallery. These are made by breaking open a pull solenoid and extending the inner tubing so that the shaft can be flipped upside down and triggered to hop out of the front edge and strike a xylophone, or Indian bell. These too are very mechanically quiet and robust based on second author's extensive experience.

Figure 5 - Trimpin BellHop outside shell tubing (left) and inside extended tubing (right).

3.2. Head

The headpiece of the *MahaDeviBot* is the robotic head that can bounce up and down at a given tempo. This was made using a pull solenoid attached to a pipe. Two masks are attached to either side and the brain is visualized by recycled computer parts from 10-year old machines which have no use in our laboratories anymore. In performance with a human musician, the head serves as a visual feedback cue to inform the human of the machine-perceived tempo at a given instance in time.

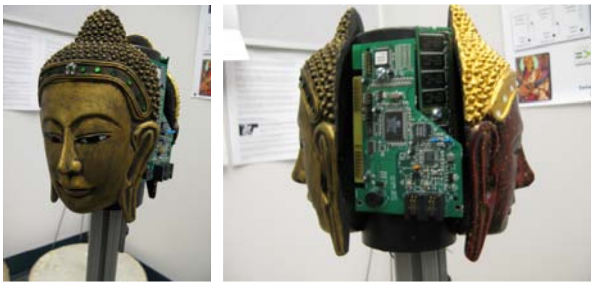

Figure 6 - The bouncing head of *MahaDeviBot*.

3.3. Haptic Feedback System

A haptic feedback system was implemented using piezo sensors attached to the frame drums and other instruments. This was to infuse the system with machine "self awareness" i.e. to know about the capabilities and limitations of its own implements. If the machine triggers a robotic drum strike and the piezo does not receive a signal, then it knows to increase the volume for the next strike. If it reaches its maximum volume ability and still no signal is received, then it knows that the mechanism is malfunctioning. This will trigger the machine to shut off and disable itself from further action during a performance to save power and reduce unnecessary mechanical noise. This feedback system is also used for the evaluation experiments described in the following section.

4. EXPERIMENTAL EVALUATION

4.1. Speed Tests

Speed tests were administered to each type of solenoid-based system using the ChucK[13] strongly-timed programming language. The frequency of successive strikes began at 1 Hz and was incremented by .01 Hz until it was observed that the mechanism was malfunctioning. The maximum speeds obtained by each device are portrayed in Figure 7.

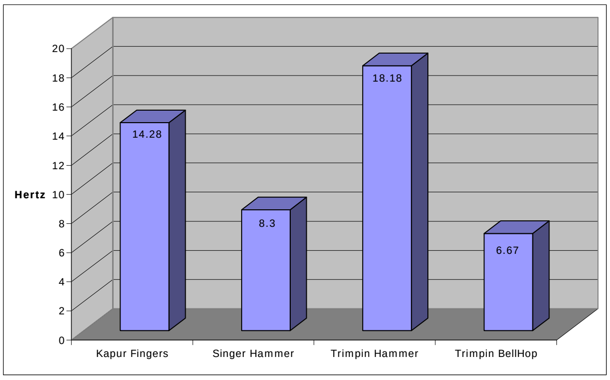

Figure 7 - Maximum speeds attainable by each robotic device.

4.2. Dynamic Range Tests

Dynamic range experimentation was administered by triggering robotic strikes with increasing strength using MIDI velocity messages ranging from 1 to 127. The piezo sensors placed on the drums measure the actual response for each dynamic level. Results are show in Figure 8.

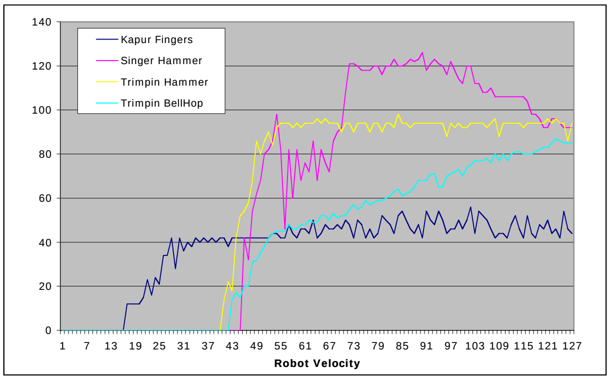

Figure 8 - Dynamic Range Testing Results.

4.3. Discussion

These experiments show that each design has different strengths and weaknesses. The Kapur Finger has moderately high speed capability reaching up to 14.28 Hz. However, it has limited dynamic range and cannot strike very loud. The Singer Hammer can strike very soft and very loud, but can only play as fast as 8.3 Hz. The Trimpin Hammer can roll at 18.18 Hz with only one finger, but does not have the dynamic capabilities seen in the Singer Hammer. The Trimpin Bellhop has the most linear dynamic response but is the slowest design.

Even though some of these design tradeoffs were expected, the quantitative evaluation provides more concrete and solid information. As an example of how these tradeoffs can influence robotic design for musical performance, the four designs are integrated into *MahaDeviBot* in the following ways: The Kapur Fingers are added to a drum with the Singer Hammer to allow large dynamic range and quick rolls from one frame drum. The Trimpin Hammer is used to perform drum rolls and are used for robotic Tabla performance. The Trimpin BellHop is used to strike bells and other instruments where volume is important and that will not be struck at high speeds.

5. FUTURE WORK

Future work includes making a completely automated framework in ChucK to evaluate robotic systems. We are also interested in designing mechanisms to allow the robot to strike at any x-, y- coordinate location. The next evolution of *MahaDeviBot* will include the use of other actuators including motors and gears.

6. ACKNOWLEDGEMENTS

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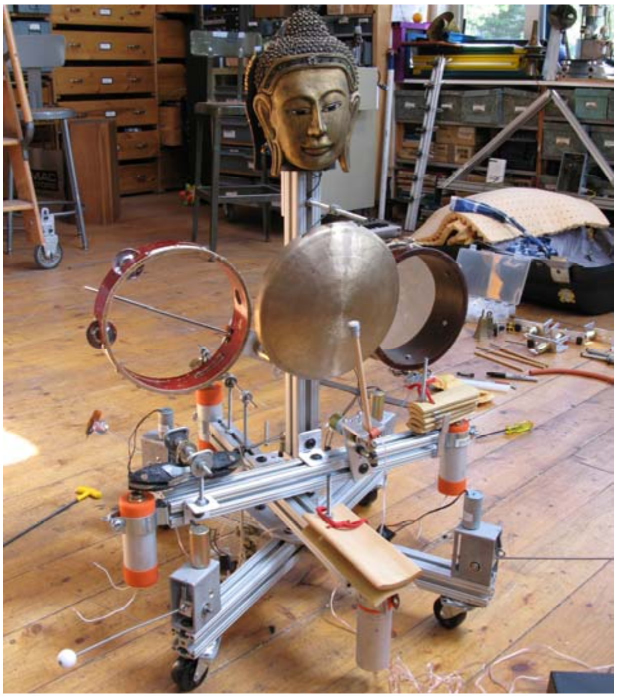

Figure 9 - Final Construction of *MahaDeviBot*

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